LIGHT WAVELENGTH CONVERTING MODULE

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a light wavelength converting module, and in particular, to a light wavelength converting module which, by using a light wavelength converting element, converts the wavelength of a fundamental wave which is emitted from a semiconductor laser.

Description of the Related Art

Conventionally, in a case in which a semiconductor laser is optically coupled to a light wavelength converting element, and the wave, which exits from the light wavelength converting element and whose wavelength has been converted such as a second harmonic, is used as recording light of a light scanning/recording device such as a laser printer, in order to make the wave whose wavelength has been converted match a scanning optical system provided at the light scanning/recording device, the plane of polarization of the wave whose wavelength has been converted must be rotated by 90°.

In order to rotate by 90° the plane of polarization of the wave whose wavelength has been converted, a half-wave plate, which imparts an optical path difference of 1/2 of the wavelength to the two polarized light components which are orthogonal, is disposed at the exiting end surface side of the light wavelength

converting element. The half-wave plate is formed from a white mica plate, a quartz crystal plate or the like which is birefringent. When the orientation of the long axis of the elliptically polarized light which is incident on the half-wave plate is θ from the main axis of the wavelength plate, the orientation of the long axis of the elliptically polarized light which exits from the half-wave plate is $-\theta$. For example, if $\theta = 45^\circ$, the elliptically polarized light incident on the half-wave plate and the elliptically polarized light exiting therefrom are orthogonal to one another. Namely, although the elliptical shapes of the polarized lights are the same, the directions of the long axes thereof are orthogonal to each other, and the directions of rotation of the polarized lights are inverted.

However, the wave whose wavelength has been converted and the fundamental wave whose wavelength has not been converted both exit from the exiting end surface of the light wavelength converting element. Further, the half-wave plate is disposed substantially orthogonal to the optical axis in order for the performances thereof to be exhibited as much as possible. When the half-wave plate is disposed at the exiting end surface side of the light wavelength converting element, a problem arises in that the fundamental wave is reflected by the half-wave plate, becomes so-called return light, again enters into the semiconductor laser, and becomes a source of noise.

Further, tilting the half-wave plate with respect to the

optical axis such that the light reflected at the half-wave plate does not become return light, has been thought of in order to overcome the aforementioned problem. However, when the half-wave plate is inclined with respect to the optical axis, the performances of the half-wave plate cannot be sufficiently exhibited.

SUMMARY OF THE INVENTION

The present invention was developed in light of the aforementioned, and an object of the present invention is to provide a light wavelength converting module which is formed to include a light wavelength converting element and a semiconductor laser which is optically coupled to the light wavelength converting element, wherein when a wavelength plate, which imparts a predetermined optical path difference to the orthogonal two polarized light components of the wave whose wavelength is converted, is provided, the generation of noise due to return light is prevented, and a wave whose wavelength is converted can be stably obtained.

In order to achieve the above object, a first aspect of the present invention is a light wavelength converting module comprising: a semiconductor laser from which a fundamental wave exits; a light wavelength converting element which is optically coupled to the semiconductor laser, and which converts a wavelength of the fundamental wave which has entered from the

semiconductor laser; a wavelength plate disposed at a light exiting side of the light wavelength converting element; and removing means, disposed between the wavelength plate and the light wavelength converting element, for removing the fundamental wave from light incident on the removing means.

In the first aspect of the present invention, the fundamental wave which exits from the semiconductor laser enters into the light wavelength converting element which is optically coupled to the semiconductor laser, and is wavelength converted by the light wavelength converting element. A wavelength plate is disposed at the light exiting side of the light wavelength converting element. The fundamental wave is removed from the light which exits from the light wavelength converting element, by a removing means which is disposed between the wavelength plate and the light wavelength converting element, and the light from which the fundamental wave is removed is incident on the wavelength plate. In this way, by providing the removing means, which removes the fundamental wave from the light incident thereon, between the wavelength plate and the light wavelength converting element, the fundamental wave can be prevented from being reflected by the wavelength plate and becoming return light. In this way, a wave whose wavelength has been converted can be obtained stably, without noise being generated at the semiconductor laser.

In the above-described light wavelength converting module, the removing means can be formed by an IR cutting filter. By using

an IR cutting filter as the removing means, the fundamental wave, which is infrared light, can be removed.

In the above-described light wavelength converting module, it is preferable that the light wavelength converting element is directly joined to the semiconductor laser. By directly joining the light wavelength converting element to the semiconductor laser, the device can be made compact.

In the above-described light wavelength converting module, a half-wave plate or a quarter-wave plate, with respect to a wave whose wavelength is converted, can be used as the wavelength plate. In a case in which a half-wave plate with respect to the wave whose wavelength is converted is used as the wavelength plate, the plane of polarization of the incident light can be rotated by 90°. In a case in which a wavelength plate of 1/4 of the wavelength with respect to the wave whose wavelength is converted is used as the wavelength plate, the incident light which is linearly polarized light can be changed into circularly polarized light.

In the above-described light wavelength converting module, the wavelength plate can be disposed substantially orthogonal to an optical axis. In order to effectively exhibit the performances of the wavelength plate, the wavelength plate is disposed substantially orthogonal to the optical axis, and preferably, so as to form an angle of 0.5° or less with a plane which is orthogonal to the optical axis. If the wavelength plate is tilted any more than that with respect to the optical axis, the extinction ratio

of the light wavelength converting module deteriorates, which is not preferable.

In the above-described light wavelength converting module, a beam splitter can be provided at a light exiting side of the wavelength plate.

In particular, a structure is preferable in which a beam splitter and a photodiode are disposed at a light exiting side of the wavelength plate, and the beam splitter and the photodiode are shielded from light. The beam splitter and the photodiode are disposed at the light exiting side of the wavelength plate and are shielded from light, so that scattered light is not incident on the photodiode.

In the above-described light wavelength converting module, a light attenuating mechanism which attenuates light passing therethrough can be provided at a light exiting side of the light wavelength converting element. When the driving current of the semiconductor laser falls within a predetermined range, a stable output without dispersion can be obtained. Thus, the light attenuating mechanism is provided at the light exiting side of the light wavelength converting element. The light passing therethrough is attenuated in accordance with the desired output light amount such that the value of the driving current of the semiconductor laser falls within a predetermined range, and stable output can be obtained.

The light attenuating mechanism is preferably provided at

a light exiting side of the light wavelength converting element and at a light entering side of the beam splitter. In a case in which the light attenuating mechanism is provided at the light entering side of the beam splitter, it suffices to provide the light attenuating mechanism at one place. Further, even in cases in which a beam splitter and a photodiode are disposed at the light exiting side of the wavelength plate and the output light is monitored, dispersion in the value of the monitor current can be suppressed.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a plan view of a light wavelength converting module of an embodiment of the present invention.

Fig. 2 is a sectional view, taken along an optical axis, of the light wavelength converting module of the embodiment.

Fig. 3 is a diagram for explaining wiring of the light wavelength converting module of the embodiment.

Fig. 4 is a circuit diagram showing a driving circuit of the light wavelength converting module of the embodiment.

Fig. 5 is a plan view of a light wavelength converting module of a second embodiment.

Fig. 6 is a graph showing an electric current vs. light output characteristic (IL characteristic) of a wavelength stabilized laser.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Hereinafter, an embodiment of a light wavelength converting module to which the present invention is applied will be described in detail with reference to the drawings.

(First Embodiment)

As shown in Fig. 1, the light wavelength converting module relating to the present embodiment includes a semiconductor laser 10 which has an oscillation wavelength in the infrared region, and which includes a first end surface (rearward exiting end surface) and a second end surface (forward exiting end surface) which opposes the first end surface; a mirror 12 which serves as a reflecting member and which, together with the forward exiting end surface of the semiconductor laser 10, forms an external resonator; and a waveguide-type light wavelength converting element 14 which converts the wavelength of the fundamental wave emitted from the semiconductor laser 10 and outputs a second harmonic.

The semiconductor laser (LD) 10 is held by a mount 16. The light wavelength converting element 14, which is formed by a second harmonic generating element (SHG), is held by a mount 18. In the state in which the semiconductor laser 10 and the light wavelength converting element 14 are held by the respective mounts, the exit portion of the semiconductor laser 10 and the waveguide portion (entrance portion) of the light wavelength converting element 14 are positioned so as to coincide with one another, so

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as to form an LD-SHG unit 20. The LD-SHG unit 20 is fixed on a base plate 22. The light wavelength converting element 14 is thereby directly joined to the forward exiting end surface of the semiconductor laser 10.

The semiconductor laser 10 is a regular semiconductor laser (laser diode) having a Fabry-Perot type (FP type) unimodal spatial mode (transverse single mode). LR (low reflectance) coatings 24A, 24B with respect to light of the oscillation wavelength, are provided at the both end surfaces (cleavage surfaces) of the semiconductor laser 10. For example, the reflectance of the LR coating 24A with respect to the fundamental wave is 30%, and the reflectance of the LR coating 24B with respect to the fundamental wave is 30%.

The light wavelength converting element 14 has a substrate 26 which is formed from a crystal in which $LiNbO_3$, which is a ferroelectric having a non-linear optical effect, is, for example, 5 mol% doped with MgO (hereinafter, this structure will be abbreviated as MgO-LN). A periodic domain inverted structure and a channel light waveguide 30 are formed at the substrate 26. At the periodic domain inverted structure, domain inverted portions 28, at which the orientation of spontaneous polarization parallel to the Z axis is inverted, is formed at a predetermined period Λ which will be described later. The channel light waveguide 30 extends along the periodic domain inverted structure. Further, an AR (transmissive) coating 32A with respect to the fundamental

wave is formed at the semiconductor laser side end surface of the light wavelength converting element 14, and an AR coating 32B with respect to the second harmonic and the fundamental wave is formed at the exiting side end surface of the light wavelength converting element 14. The method of fabricating the waveguide type light wavelength converting element 14 having a periodic domain inverted structure is disclosed in detail in Japanese Patent Application Laid-Open (JP-A) No. 10-254001.

The forward exiting end surface of the light wavelength converting element 14 is polished at an incline, and an inclined surface is formed thereat. The inclined surface is inclined, with respect to a plane orthogonal to the direction in which the channel light waveguide 30 extends, at at least an angle θ ($3^\circ \leqq \theta$) in the direction in which the channel light waveguide 30 extends. Due to the forward exiting end surface, including the light waveguide end surface, being polished at an incline in this way, the fundamental wave is prevented from entering again into the channel waveguide 30, and the amount of return light which returns to the semiconductor laser 10 is decreased. Note that the forward exiting end surface of the light wavelength converting element 14 may be polished orthogonally with respect to the optical axis.

A collimator lens 36, which makes parallel a laser beam (backward exiting light) 34R which exits from the rearward exiting end surface of the semiconductor laser 10 in a state of being scattered light, is mounted to the LD-SHG unit 20. The LD-SHG unit

20 and the collimator lens 36 are sealed airtight, together with dry air or an inert gas such as dry nitrogen, in a package 38 which serves as an airtight sealing member, and are fixed within the package 38. Any of a distributed refractive index rod lens such as a SELFOC lens (trade name), an aspherical lens, and a spherical lens may be used as the collimator lens 36.

A window hole 40A, through which the backward exiting light 34R from the semiconductor laser 10 passes, and a window hole 40B, through which forward exiting light 62 from the light wavelength converting element 14 passes, are formed in the package 38. The window hole 40A and the window hole 40B are covered by a transparent window plate 42A and a transparent window plate 42B, respectively, such that the airtight state is maintained. Further, a wire removal portion 44, which fits together with a wire removal hole so as to keep a low melting point glass or the like in an airtight state, is formed at the package 38. Two wires 46A, 46B, which are bound to the electrodes of the semiconductor laser 10, pass through and are pulled-out from the wire removal portion 44.

The package 38, together with the mirror 12, is fixed on a base plate 48 with the LD-SHG unit 20 and the collimator lens 36 sealed in an airtight state. An AR coating 50 is formed on the laser beam incident side surface of the mirror 12. An HR coating 52 is formed on the surface, of the mirror 12, which is at the side opposite the incident side surface. A narrow-band bandpass filter 56 which serves as a wavelength selecting element and which

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is held rotatably at a holder 54, a pair of total reflection prisms 58A and 58B for bending back the optical path of the laser beam 34R by substantially 180°, a pair of total reflection prisms 58C and 58D for bending back by substantially 180° the optical path which was bent back by substantially 180° by the pair of total reflection prisms 58A and 58B, and a collective lens 60 for converging the laser beam 34R, which has been made into parallel light, on the surface of the HR coating 52 of the mirror 12, are disposed in that order between the window plate 42A of the package 38 and the mirror 12, and are fixed on the base plate 48. The HR coating 52 of the mirror 12 preferably has a reflectance of 95% with respect to the fundamental wave.

The semiconductor laser 10 and the mirror 12 are disposed such that the resonator length (i.e., the optical length from the forward exiting end surface of the semiconductor laser 10 to the surface of the HR coating 52 of the mirror 12) of the external resonator, which is formed by the mirror 12 and the forward exiting end surface of the semiconductor laser 10, is longer than the coherent length of the fundamental wave exiting from the semiconductor laser. The coherent length L of the fundamental wave is the intrinsic coherent distance of that laser beam, and can be calculated in accordance with the following formula, where λ is the wavelength of the laser beam and $\Delta\lambda$ is the spectral width.

$$L = \lambda^2 / 2\pi n \Delta\lambda$$

Because the coherent length L of the fundamental wave is

generally about 100 mm, the resonator length of the external resonator can be made to be a length which, for example, exceeds 100 mm.

Further, a collimator lens 64 which makes into parallel light a second harmonic 62 (including a fundamental wave 34) which exits from the forward exiting end surface of the light wavelength converting element 14, an IR cutting filter 66 which removes the infrared light components from the second harmonic 62 (including the fundamental wave 34) which has been made into parallel light, a half-wave plate 67 which rotates by 90° the polarization direction of the second harmonic 62, a half-mirror 68, and a photodiode 70 are disposed at the outer side of the window plate 42B of the package 38, and are fixed on the base plate 48. An aspherical lens which has little aberration is preferably used as the collimator lens 64. Further, the half-mirror 68 and the photodiode 70 are light-shielded, by a light shielding plate 73, from the optical system forming the external resonator, such that scattered light is not incident on the photodiode 70.

The IR cutting filter 66 is disposed at an incline with respect to the optical axis. The half-wave plate 67 is disposed substantially orthogonal with respect to the optical axis, and preferably, so as to form an angle of no more than 0.5° with a plane which is orthogonal to the optical axis. This is because, if the half-wave plate 67 is inclined more than 0.5° with respect to the optical axis, the extinction ratio of the light wavelength

converting module deteriorates.

As shown in Fig. 2, the base plate 48 is fixed to a setting stand 72. A Peltier element 74 is disposed between the base plate 48 and the setting stand 72. Each of the optical elements fixed to the base plate 48 are adjusted to predetermined temperatures by this Peltier element 74. The respective optical elements fixed to the base plate 48 are, together with the base plate 48 and the Peltier element 74, covered by a cover 75 for dustproofing whose laser beam exiting portion is transparent.

A knife edge 76, which serves as a light shielding plate for beam reshaping, is disposed and fixed, on the setting stand 72, in a vicinity of the position of convergence of the second harmonic 62. As will be described later, the second harmonic 62, which exits after propagating through the channel light waveguide 30 of the light wavelength converting element 14 in a first-order mode, has a side lobe at a portion which is beneath, in the vertical direction (the direction of thickness of the substrate 26), the setting surface of the setting stand 72. However, the knife edge 76 is disposed so as to cut this side lobe portion. A second harmonic 62G, which is obtained by the side lobe being cut by the knife edge 76, is a Gaussian beam whose light intensity distribution within the beam cross-section is a substantially Gaussian distribution. Note that, in the present embodiment, the knife edge 76 is disposed in a vicinity of the position of convergence of the second harmonic 62. However, the knife edge 76 may be disposed

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so as to be fit tightly to or to be adjacent to the forward exiting end surface of the light wavelength converting element 14.

As shown in Fig. 3, the semiconductor laser 10 is connected to a driving circuit 78 via the wires 46A, 46B which are pulled-out to the exterior of the cover 75 for dustproofing. The schematic structure of the driving circuit 78 is shown in Fig. 4. The driving circuit 78 is formed from a DC power source circuit 80 having an automatic power control mechanism (APC), an AC power source 84, and a bias T 88. The bias T is formed from a coil 82 and a capacitor 86. A high frequency wave, which has been emitted from the AC power source 84 and has passed through the capacitor 86, is superimposed on the DC power source component, which has been emitted from the DC power source circuit 80 and has passed through the coil 82, and the current on which the high frequency wave has been superimposed is applied to the semiconductor laser 10. In order to reduce the noise of the second harmonic which is outputted, the frequency of the high frequency wave which is superimposed is preferably 300 to 400 MHz, and the degree of modulation is preferably 30 to 70%.

Two wires 71A, 71B are bonded to the electrodes of the photodiode 70, and are pulled-out to the exterior of the cover 75 for dustproofing. The photodiode 70 is connected, via the wires 71A, 71B which have been pulled-out to the exterior of the cover 75 for dustproofing, to the DC power source circuit 80 which is equipped with the APC. The amount of current which is applied to

the semiconductor laser 10 is controlled by the APC such that the light output of the second harmonic 62 is a predetermined value. Further, the Peltier element 74 is connected to a temperature controller 90. A thermistor (not shown), for adjusting the temperature within the device, is provided at the interior of the device which is covered by the cover 75 for dustproofing. This thermistor as well is connected to the temperature controller 90. On the basis of the output of the thermistor, the temperature controller 90 controls the Peltier element 74 such that the interior of the device is maintained in a temperature range at which the optical system does not freeze in the usage environment. (For example, if the usage environment temperature is 30°, the temperature range at which the interior of the device is maintained is 30° or more.)

Next, operation of the light wavelength converting module will be explained.

The laser beam 34R (the backward exiting light), which is emitted from the semiconductor laser 10 toward the rear and not toward the light wavelength converting element 14, is made into parallel light by the collimator lens 36. The laser beam 34R which has been made into parallel light passes through the narrow-band bandpass filter 56. Thereafter, the optical path is bent back 180° by the pair of total reflection prisms 58A and 58B, and is again bent back by 180° by the other pair of total reflection prisms 58C and 58D. The laser beam 34R is then collected by the collective

lens 60, and is converged on the mirror 12. The laser beam 34R which is reflected at the mirror 12 follows back the optical path until then, and is fed-back to the semiconductor laser 10. Namely, in this device, the external resonator of the semiconductor laser 10 is formed by the mirror 12 and the forward end surface of the semiconductor laser 10.

The wavelength of the laser beam 34R which is fed-back is selected by the narrow-band bandpass filter 56 which is disposed in the external resonator. The semiconductor laser 10 oscillates at the selected wavelength, and the selected wavelength changes in accordance with the rotational position of the narrow-band bandpass filter 56. Thus, by appropriately rotating the narrow-band bandpass filter 56, the oscillation wavelength of the semiconductor laser 10 is selected to be and can be locked (fixed) at a wavelength which phase-matches the period of the domain inverted portions 28 of the light wavelength converting element 14.

On the other hand, the laser beam 34, which is locked to a predetermined wavelength and has been emitted from the forward side of the semiconductor laser 10, enters into the channel light waveguide 30. The laser beam 34 is waveguided through the channel light waveguide 30 in the TE mode, and is phase-matched (so-called pseudo phase matching) at the periodic domain inverted region thereof, and is converted into the second harmonic 62 whose wavelength is 1/2 (e.g., when the central wavelength of the laser

beam 34 is 950 nm, the wavelength of the second harmonic 62 is 475 nm). This second harmonic 62 also propagates through the channel light waveguide 30 in the guided wave mode, and exits from the light waveguide end surface.

From research conducted by the present inventors and others, it has been learned that the overlapping integral, with the fundamental wave, of a second harmonic which propagates through a light waveguide in a first-order mode, is greater than that of a second harmonic which propagates through a light waveguide in a zero-order mode. Namely, the wavelength converting efficiency is better when a fundamental wave and a second harmonic which propagates in a first-order mode are phase-matched. Thus, in the present embodiment, the period Λ of the periodic domain inverted structure is set such that the second harmonic 62, which propagates through the channel light waveguide 30 of the light wavelength converting element 14 in the first-order mode, and the fundamental wave 34 are pseudo phase matched. Specifically, given that the effective refractive index of the light waveguide with respect to the fundamental wave is n_{ω}, the effective refractive index of the light waveguide with respect to the second harmonic is $n_{2\omega}$, and the wavelength of the fundamental wave is λ_F, the period Λ is set such that the following formula is satisfied.

$$n_{2\omega} - n_{\omega} = \lambda_F / 2\Lambda$$

Further, the laser beam 34 whose wavelength is not converted also exits from the light waveguide end surface in a state of being

scattered light. The laser beam 34, together with the second harmonic 62, are made into parallel light by the collimator lens 64. After the light which exits from the light waveguide end surface of the light wavelength converting element 14 is made into parallel light by the collimator lens 64, the fundamental wave 34 is removed by the IR cutting filter 66 such that the second harmonic 62 is separated, and the polarization direction of the second harmonic 62 is rotated 90° by the half-wave plate 67, and the second harmonic 62 exits. One portion of the second harmonic 62 which has exited is reflected by the half-mirror 68 and detected by the photodiode 70. Power control of the laser beam is carried out on the basis of these results of detection.

As described above, in the light wavelength converting module relating to the present embodiment, the polarization direction of the second harmonic which exits from the light wavelength converting element is the direction parallel to the setting stand. However, by using the half-wave plate for polarization control, a second harmonic which is polarized in a direction orthogonal to the setting stand can be obtained. At this time, the half-wave plate is disposed between the light wavelength converting element and the IR cutting filter. Thus, the fundamental wave is removed from the light which reaches the half-wave plate. Accordingly, the fundamental wave is not reflected by the half-wave plate and does not become return light, noise due to return light returning to the semiconductor laser is not generated,

and a wave whose wavelength is converted can be obtained stably.

Further, at the light wavelength converting module relating to the present embodiment, the semiconductor laser and the light wavelength converting element are directly joined. Thus, with a simple structure which does not utilize a solid state laser crystal, the fundamental wave exiting from the semiconductor laser can be directly wavelength-converted by the light wavelength converting element. The degrees of freedom in selecting the oscillation wavelength increase, and high speed modulation can be carried out.

At the light wavelength converting module of the present embodiment, because only a small number of parts, including the semiconductor laser and the light wavelength converting element, are sealed airtight within the package, fabrication is easy. Moreover, because the number of parts which are sealed airtight is few, deterioration over time and the like of the parts which are sealed due to the gasses generated from the respective parts can be prevented.

Further, the light wavelength converting module of the present embodiment utilizes a mirror in which an AR coating is formed at the surface at the laser beam incident side and an HR coating is formed at the surface at the side opposite the incident side surface. Thus, the beam spot diameter at the mirror surface becomes large, it is difficult for dust and dirt to adhere to the mirror surface, and a deterioration in the reflectance of the

mirror due to the adhering of dust and dirt can be prevented.

Moreover, in the light wavelength converting module relating to the present embodiment, the laser light emitted from the semiconductor laser is locked to a predetermined wavelength. Thus, a wave whose wavelength has been converted can be outputted stably. (Hereinafter, a semiconductor laser, at which the laser light emitted therefrom can be locked to a predetermined wavelength, is called a "wavelength stabilized laser".)

Further, at the time of locking the wavelength, by making the resonator length of the external resonator longer than the coherent length of the fundamental wave, interference due to return light is eliminated, and the linearity of the IL characteristic (the light output characteristic with respect to the driving current) can be maintained. In a structure provided with an external resonator, lights of different optical path lengths, such as return light from the external resonator, are combined and become the exiting light. However, because lights of different optical path lengths interfere with one another, when the light interfering state changes, there are cases in which the linearity of the IL characteristic deteriorates. For example, when the current applied to the semiconductor laser is increased, the semiconductor laser itself generates heat, and the refractive index and the length of the semiconductor laser change. Thus, the oscillation wavelength of the semiconductor laser changes. Such a change in the oscillation wavelength changes the light

interfering state, and the linearity of the IL characteristic of a wavelength stabilized laser deteriorates. However, as in the present embodiment, when the resonator length of the external resonator becomes longer than the coherent length of the fundamental wave, even if the resonator length of the external resonator varies somewhat, there is no great effect on the oscillation wavelength of the semiconductor laser, and the linearity of the IL characteristic of a wavelength stabilized laser is improved.

Further, in the present embodiment, by sealing airtight a small number of parts including the semiconductor laser and the light wavelength converting element, changes in the humidity and the atmospheric pressure of the usage environment can be sufficiently addressed. Thus, in the light wavelength converting module of the present embodiment, a wave whose wavelength has been converted can be stably output. Note that, in the present embodiment, although the resonator length of the external resonator is long as described above, the light wavelength converting module is contrived to be made more compact by the external resonator being made to be a structure in which the optical path is bent back.

Further, because the light wavelength converting module of the present embodiment uses a transverse single mode semiconductor laser, the problem of transverse mode hopping does not occur.

In the light wavelength converting module of the present embodiment, the obtained second harmonic is a Gaussian beam. Thus, the recording light can be narrowed to a smaller spot, and can be suitably used as the recording light source of a light scanning/recording device.

Further, in the light wavelength converting module of the present embodiment, the semiconductor laser is modulated and driven by a high frequency wave being superimposed on the driving current. Thus, longitudinal mode competition is suppressed. When the transmission band of the wavelength selecting element is set to be wider than the Fabry-Perot mode interval between both cleavage surfaces of the semiconductor laser, the semiconductor laser oscillates in a plurality of longitudinal modes. In this state, even if the driving current of the semiconductor laser is fixed, a phenomenon known as longitudinal mode competition, in which the rate of the power distribution to each longitudinal mode varies depending on the time, occurs. However, in the light wavelength converting module of the present embodiment, the semiconductor laser is modulated and driven by the high frequency wave being superimposed on the driving current. Thus, the driving current does not accumulate at a region at which longitudinal mode competition occurs.

(Second Embodiment)

As shown in Fig. 5, a light wavelength converting module relating to the present embodiment has the same structure as that

of the light wavelength converting module relating to the first embodiment, except that a light attenuator 92, which serves as a light attenuating mechanism, is provided between the IR cutting filter 66 and the half-wave plate 67. Thus, portions of the present embodiment which are the same as those of the first embodiment are denoted by the same reference numerals, and description thereof is omitted.

As described above, the collimator lens 64 which makes into parallel light the second harmonic 62 (including the fundamental wave 34) which exits from the forward exiting end surface of the light wavelength converting element 14, the IR cutting filter 66 which removes the infrared light components from the second harmonic 62 (including the fundamental wave 34) which has been made into parallel light, the light attenuator 92 which attenuates the incident second harmonic 62 to a predetermined light amount, the half-wave plate 67 which rotates by 90° the polarization direction of the second harmonic 62, the half-mirror 68, and the photodiode 70 are disposed at the outer side of the window plate 42B of the package 38, and are fixed on the base plate 48.

The light attenuator 92 is an element which attenuates, at a predetermined rate of attenuation, the amplitude (intensity) of the light incident thereon. Light attenuators are classified into absorbing types which reduce the amount of light transmitted therethrough by light absorption, non-absorbing types which reduce the amount of light transmitted therethrough by a method

other than light absorption, wavelength selection types and wavelength non-selection types which attenuate the amplitude of incident light of a predetermined wavelength, fixed types which have a fixed rate attenuation, variable types whose rate of attenuation can be varied, and the like. Examples of a light attenuator which is an absorbing type and a wavelength non-selection type are ND filters and the like. An example of a light attenuator which is a non-absorbing type and a wavelength selection type is a dielectric multilayer film. An example of a light attenuator which is a wavelength non-selection type and a variable type is a combination of two polarizers which can change the direction of the axis of transmission. In the present embodiment, an ND filter is used, but another type of light attenuator may be used.

After the light which exits from the light waveguide end surface of the light wavelength converting element 14 is made into parallel light by the collimator lens 64, the fundamental wave 34 is removed by the IR cutting filter 66 such that the second harmonic 62 is separated. The second harmonic 62 is attenuated by the light attenuator 92 to a predetermined light amount, and is made incident on the half-wave plate 67. The polarization direction of the second harmonic 62 is rotated 90° by the half-wave plate 67, and the second harmonic 62 exits. One portion of the second harmonic 62 which has exited is reflected by the half-mirror 68 and detected by the photodiode 70. Power control of the

laser beam is carried out on the basis of these results of detection.

Here, the role of the light attenuator 92 will be described in further detail. The IL characteristic of a wavelength stabilized laser is shown in Fig. 6. As shown by the solid line in Fig. 6, when the driving current falls within a predetermined range, the light output of the wavelength stabilized laser is stable. However, for example, when an attempt is made to obtain a desired output light amount Ld, the driving current falls outside of the predetermined range, and dispersion arises in the light output of the wavelength stabilized laser. At this time, as shown by the dashed line in Fig. 6, by attenuating the output light of the wavelength stabilized laser at a predetermined ratio, the desired output light amount Ld can be stably obtained at a driving current which falls within the predetermined range.

In accordance with the light wavelength converting module relating to the present embodiment, the same effects as those of the first embodiment can be obtained. In addition, by providing the light attenuator, which attenuates the light transmitted therethrough, between the IR cutting filter and the half-wave plate, the transmitted light can be attenuated in accordance with a desired output light amount such that the value of the driving current of the semiconductor laser falls within a predetermined range, and a stable output can be obtained. Further, in the present embodiment, the second harmonic which is reflected by the

half-mirror is detected by the photodiode and monitored. By providing the light attenuator at one place at the light exiting side of the half-mirror, dispersion in the value of the monitor current can be suppressed.

In the above-described second embodiment, although an example is described in which the light attenuator is provided between the IR cutting filter and the half-wave plate, the light attenuator may be disposed at any position at the light exiting side of the light wavelength converting element. However, in a case in which the collimator lens 64, the IR cutting filter 66, the half-wave plate 67, and the half-mirror 68 are disposed in that order at the light exiting side of the wavelength converting element 14 as shown in Fig. 1, it is preferable to provide the light attenuator at the light exiting side of the collimator lens 64, from the standpoint of preventing return light due to reflection from the light attenuator. In a case in which an ND filter is used as the light attenuator, the problem of return light due to reflection does not arise, and thus, the light attenuator may be provided between the wavelength converting element 14 and the collimator lens 64. Further, as shown in Fig. 1, in the case of a structure in which a portion of the exited second harmonic 62 is reflected at the half-mirror 68 and detected by the photodiode 70, it is preferable to provide the light attenuator at the light incident side of the half-mirror 68. When the light attenuator is provided at the light incident side of the

half-mirror 68, light attenuators must be provided at two places.

In the above-described second embodiment, an example is described in which a light attenuator is provided as the light attenuating mechanism. However, it suffices to not use a light attenuator, and instead, to provide a light attenuating mechanism by forming a coating for adjusting the light transmittance on another part which is disposed at the light exiting side of the light wavelength converting element. For example, in the light wavelength converting module shown in Fig. 1, it is possible to form a coating for adjusting the light transmittance, at at least one of the collimator lens 64, the IR cutting filter 66, the half-wave plate 67 and the half-mirror 68.

In the above-described first and second embodiments, an example is described in which total reflection prisms are used to bend back the optical path of the external resonator. However, instead of total reflection prisms, total reflection mirrors may be used. In this case, the total reflection mirrors are disposed such that the reflecting surfaces thereof correspond to the positions of the inclined surfaces of the total reflection prisms.

In the above-described first and second embodiments, an example is described in which a half-wave plate is used as the wavelength plate. However, the type of the wavelength plate can be appropriately changed in accordance with the purpose of use of the light wavelength converting module. For example, in a case in which it is desired to obtain circularly polarized light as

the output light of the light wavelength converting module, a quarter-wave plate may be used in place of the half-wave plate. Note that, other than a half-wave plate and a quarter-wave plate, wavelength plates having various phase differences, such as an eighth-wave plate, a three-quarter-wave plate, and the like, can be obtained.

In the above-described first and second embodiments, an example is described in which the semiconductor laser and the light wavelength converting element are joined directly. However, the semiconductor laser and the light wavelength converting element may be joined via a lens.

In the above-described first and second embodiments, wavelength locking can be mitigated and the linearity of the IL characteristic can be improved by finely adjusting the positions at which the members forming the external resonator are disposed or the positions at which the members disposed within the external resonator are disposed, so as to reduce the return light to the semiconductor laser due to the external resonator. To describe this concretely with reference to Fig. 1, for example, by setting the collimator lens 36 slightly closer toward the semiconductor laser 10 such that the spread angle θ of the collimator lens falls within the range $0^\circ < \theta < 30^\circ$, the return light to the semiconductor laser 10 is decreased, and the linearity of the IL characteristic is improved. This depends on the performances of the end portion of the collective lens 60 being poor, vignetting

occurring due to spreading at the collective lens 60, and the like. Further, for example, by setting the mirror 12 slightly closer to the semiconductor laser 10 such that the position at which the mirror 12 is disposed is offset from the focal point position of the collective lens 60, the return light to the semiconductor laser 10 is decreased, and the linearity of the IL characteristic is improved.

In accordance with the present invention, the light wavelength converting module, which is formed to include a light wavelength converting element and a semiconductor laser which is optically coupled to the light wavelength converting element, has the effect that, when a wavelength plate, which provides a predetermined optical path difference, is provided between two orthogonal polarized light components of a wave whose wavelength has been converted, the generation of noise due to return light is prevented, and a wave whose wavelength has been converted can be obtained stably.